NATIONAL SYMPOSIUM ON URBAN HYDROLOGY AND SEDIMENT CONTROL
(University of Kentucky, Lexington, KY., July 28-31, 1975)

SOME ASPECTS OF SEDIMENTATION POND DESIGN

by

J. A. Bondurant
USDA-ARS, Western Region
Kimberly, Idaho 83341

C. E. Brockway
Water Resources Research Institute
University of Idaho
Kimberly, Idaho 83341

M. J. Brown
USDA-ARS, Western Region
Kimberly, Idaho 83341

Abstract

Erosion and sedimentation are normal geologic processes which are usually accelerated by irrigating agricultural lands. Of the sediment in irrigation runoff, 70% was removed in a sedimentation pond. Removal efficiency correlated well with flow rate and sediment concentration. Pond design should provide maximum velocity reduction early in ponding, allow adequate storage space for the larger particles, and decrease the flow depth toward the outlet while maintaining a constant forward velocity. This requires a fan-shaped pond, deeper at the inlet and decreasing in depth while increasing in width toward the outlet. This pond shape fits well into natural swales or draws.

Introduction

Erosion, sediment production, and sedimentation are normal geologic processes which may be accelerated or retarded by man's activities. Tilling of soils, irrigation, construction, and overgrazing of rangeland accelerate erosion; while rangeland improvement, terracing, grass waterways, and other conservation measures decelerate erosion. Erosion and sedimentation, whether at a natural or accelerated rate, may impede man's activities. Siltation of harbors and rivers, for example, may impede shipping, and increased flooding may deposit silt on farm fields and in urban areas. Erosion and sedimentation control has been encouraged for many years, but additional emphasis has resulted from passage of recent Federal legislation (Public Law 92-500). This law has sections covering both diffuse water runoff sources and point runoff sources. It also covers methods for control of sediment sources or alleviation of sediment effects on other areas and streams.

Background

Designing facilities for sediment removal from water has been studied mainly for municipal water treatment. Much of the early work, like that reported by Hazen (1904), was empirical and sedimentation basins were designed on a retention time basis, a concept which still persists to some extent. Most of the current design of sedimentation facilities is based on the work of Camp (1936, 1946, 1953), who utilized Stokes' law (Stokes, 1851) to analyze pond design in relation to the particle settling velocity and the forward velocity in the pond. Camp showed that sedimentation basins should be designed so that suspended particles settle within as short a distance as possible and yet allow adequate space for sediment accumulation. This work was further extended by development of the 'slanted tube settler' (Culp, 1969) where settling depths were limited to about 0.2 ft, with forward velocities low enough to avoid resuspending settled particles. Density currents are formed in natural or very large sedimentation basins like reservoirs behind large dams, and sediment is transported through the reservoir because forward velocity is not uniformly distributed (Howard, 1953).

Predicting the sediment load is a major problem in designing sedimentation ponds. In a recent study of water and sediment balances on two large irrigated tracts in southern Idaho, Brown, et al. (1974) found that one tract in predominantly sandy soil had a positive sediment balance, i.e., less sediment flowed from the irrigated tract with the runoff water than was taken in with the input water although movement of sediment within the irrigated area was considerable. The other large irrigated tract, with predominantly silt loam soils, had a net output of sediment. Within both irrigated tracts, movement of sediment was considerable. The main drains from the sandy tract also have less gradient, so most of the sediment settles in the canals. Both tracts take water from the Snake River at the same diversion point.

Ballard (1975), in a study of sediment ponds for individual fields, reported that sediment concentrations and total sediment loads from individual irrigated fields varied considerably, depending upon the crop and the tillage practice.

Design Considerations

Settlement of a particle from a flowing stream requires reducing the forward velocity of the stream so that the resultant velocity, considering the forward velocity and the settling velocity of the particle, allows the particle to reach the bottom of the pond before reaching the exit. The settling velocity of most sediment particles can be predicted using Stokes' law:

$$V = \frac{2\,gr^2(\rho_p-\rho)}{9\eta}$$

where V is the velocity of fall; g is the acceleration due to gravity; ρ_p is the density of the particle; ρ is the density of the liquid; r is the radius of the particle; and η is the absolute viscosity of the liquid. Stokes' law is based on the assumptions that (1) particles must be large enough that they are not affected by Brownian movement, (2) all particles maintain their shape, size, and individuality during settling and settle without interference from one another, (3) the particles be rigid and smooth, (4) Reynold's number based on fall velocity, particle diameter, and fluid viscosity not exceed 10. Then, the viscosity of the liquid remains the only resistance to fall of particles. Within these limits, particles larger than silt cannot be separated accurately by using Stokes' law. This, however, is not a problem in sedimentation basin design since the actual settling velocity of sand particles is faster than indicated by Stokes' law and they settle earlier than predicted. Sediment pond design based on Stokes' law would be conservative for sand and larger particles.

The minimum forward velocity and the distance necessary for particles to settle 1 ft is shown in Fig. 1. For example, if the forward velocity can be reduced to 0.1 ft/sec, a distance of only 10 ft is required for a sand-size particle to settle 1 ft. With a 0.1 ft/sec forward velocity and 1 ft depth, a 1000-ft pond, which is about the limit of farm size ponds, would retain only particles larger than 5 μ. This is generally larger than the clay size fraction. For a given pond, the particle size that would be retained can be estimated assuming a uniform forward velocity through the pond.

To settle all large particles and as many of the small ones as possible, both the forward velocity and the depth of settling should be reduced. This requires obtaining maximum velocity reduction early in the pond, allowing adequate storage area for larger particles, and decreasing flow depth toward the outlet. To maintain a constant forward velocity while decreasing pond depth requires increasing the width so that the flow area is constant. Maintaining a uniform forward velocity and preventing channelized flow is a problem. Camp (1946) recommended long, narrow, rectangular ponds to develop a uniform velocity profile and prevent short circuiting. For narrow

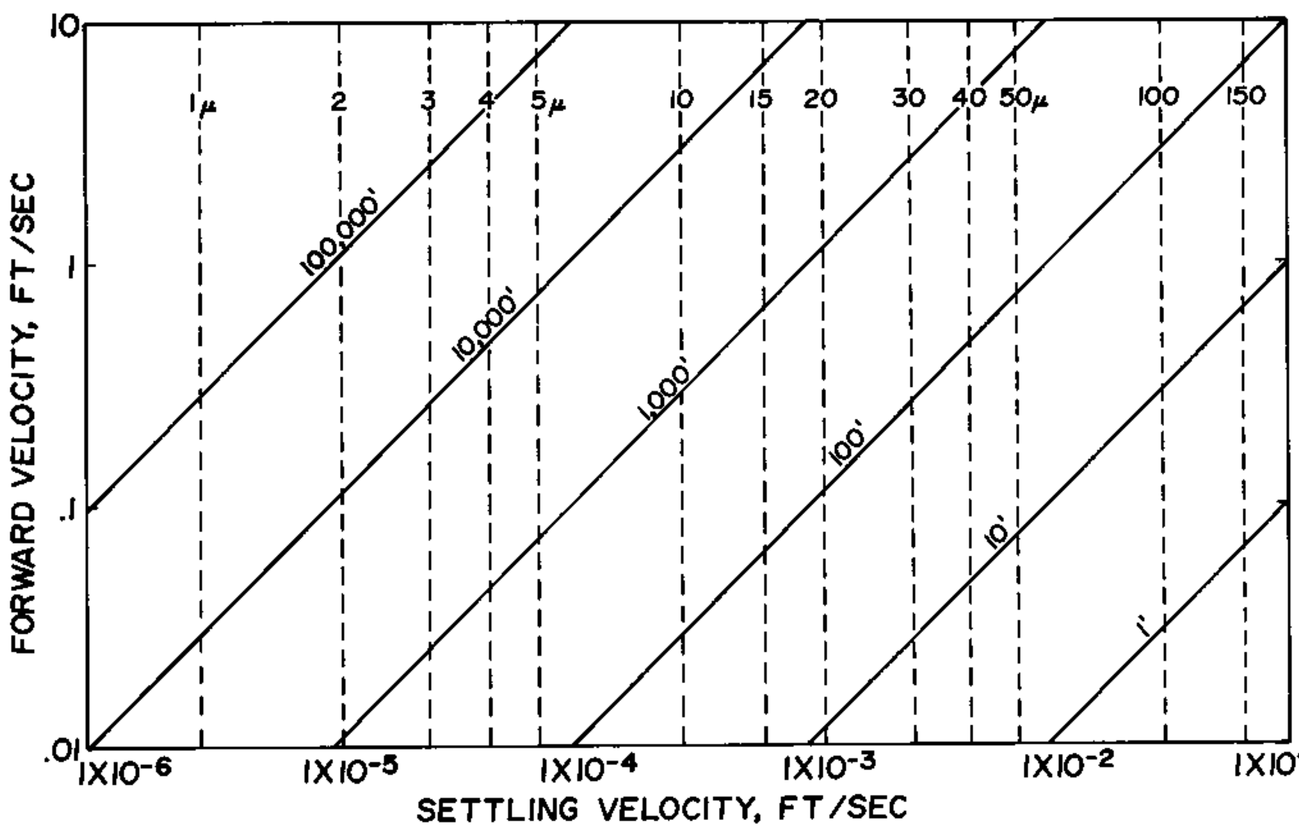


FIG. 1. - Pond length required for quartz particles to settle one foot at various forward velocities, using Stokes' law.

rectangular ponds, entrance and exit conditions each require about 5% of the total length of the pond. In a pond where the depth decreases from the inlet to the outlet, short circuiting can be prevented using a full-width, skimming-type weir exit. Accurately leveling the exit weir provides reasonably uniform overflow depths and essentially prevents short circuiting.

To remove clay particles, techniques other than direct sedimentation are employed, like chemical flocculation or vegetated filter strips. Some flocculation is natural in waters, and larger particle sizes are created which settle faster. Vegetated filter strips very effectively remove sediment from streams, but must endure inundation without deleterious effects. Few grass varieties can survive under continuous inundation. Probably the best is Reed canary grass (*Phalaris arundenaces*). Rice (*Oryza sativa*) could be used annually. Reed canary grass is a persistent and proliferant grass under these conditions and could become a pest downstream. A grass filter should also be able to reestablish itself, after the accumulated depth of sediment is removed.

Cleaning sediment ponds is another consideration. To remain effective, a pond must be available for both sediment storage and reduction of flow velocity. Many ponds require annual or biannual cleaning and the method of cleaning should be considered in sizing a pond. The easiest way to clean a pond is to use a dragline. If the pond dries during the off season, it can be cleaned with a front-end loader or a carryall.

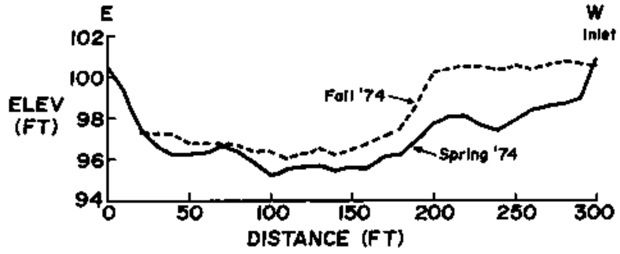
Field Studies

Two sediment ponds in southern Idaho have been studied in detail. One is 60 ft wide, 500 ft long, and about 5 ft deep. It is located on the Northside Canal Company's K-Lateral, which serves an area of about 6000 acres with an average flow rate of about 10 cfs. The second pond, located on the Snake River Conservation Research Center (SRCRC), Kimberly, Idaho, was originally 200 ft long, 40 ft wide, and 4 ft deep. In the spring of 1974 it was lengthened to 300 ft. However, the new portion was only dug to approximately 2 ft depth due to a strongly silica cemented layer. This pond serves about 70 acres.

The K-Lateral pond is equipped with an 8-ft suppressed weir and the discharge head is measured with a water stage recorder. Sediment concentrations were measured by sampling weekly in 1972 and 1974, and three times weekly in 1973. Samples (10 liter) were taken and sediment concentrations were determined. The SRCRC pond flow was measured with a 6-in Parshall flume. This pond is constructed with a full-width overflow weir exit. Volumes of sediment collected each season have been determined by surveying techniques and sampling.

Results and Discussion

A profile of the SRCRC pond after the 1974 season (Fig. 2) shows that sediment deposition filled the inlet end, essentially to the overflow depth. The deposited sediment formed a uniform delta across the inflow end. By the end of the season, the delta extended 100 ft into the pond. The depth of sediment collected then tapered off to approximately 0.5 ft at the pond outlet. Particle size analysis and density data showed that the clay content in the settled material increased with distance through the



	30'	125'	175'	235'
SAND %	9	10	18	16
SILT %	62	65	62	68
CLAY %	29	24	20	16
DENSITY				
Gm/cc	1.19	1.11	1.22	1.29
Lb/Ft^3	74	69	76	80

Figure 2. Sedimentation profile, particle size distribution and bulk density of sediments, SRCRC pond, 1974.

pond, from 16% clay near the pond inlet to 29% near the outlet. Bulk densities varied from 69 to 81 lb/ft^3 (1.1 to 1.3 g/cm^3). The median flow rate through the SRCRC pond was between 0.4 and 0.5 cfs, with extreme flows ranging between 0 and 1.5 cfs (Fig. 3). Total flow through this pond was 92 ac/ft in 1973

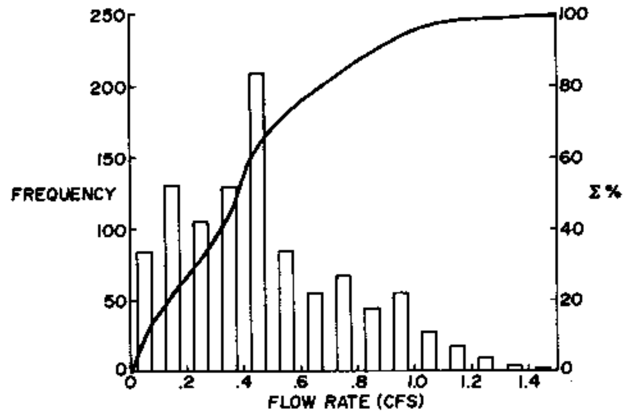


Figure 3. Flow rate frequency distribution, SRCRC pond, 1974.

and 120 ac/ft in 1974. Periodic sampling indicated that sediment removal efficiencies ranged from 56 to 96%. Inflow concentrations ranged from 40 to 8400 ppm and outflow concentrations ranged from 10 to 300 ppm.

Flow rate also affected the efficiency of sedimentation ponds. Better removal efficiencies were obtained at higher flow rates. This was attributed mainly to the difference in concentrations of the various particle sizes in the flow during the high flow rates. At low flow rates, larger particles settled in canals and approach channels and did not move into the sedimentation pond; whereas at high flow rates this material moved but was easily removed by ponding. At low flow rates, only the smaller

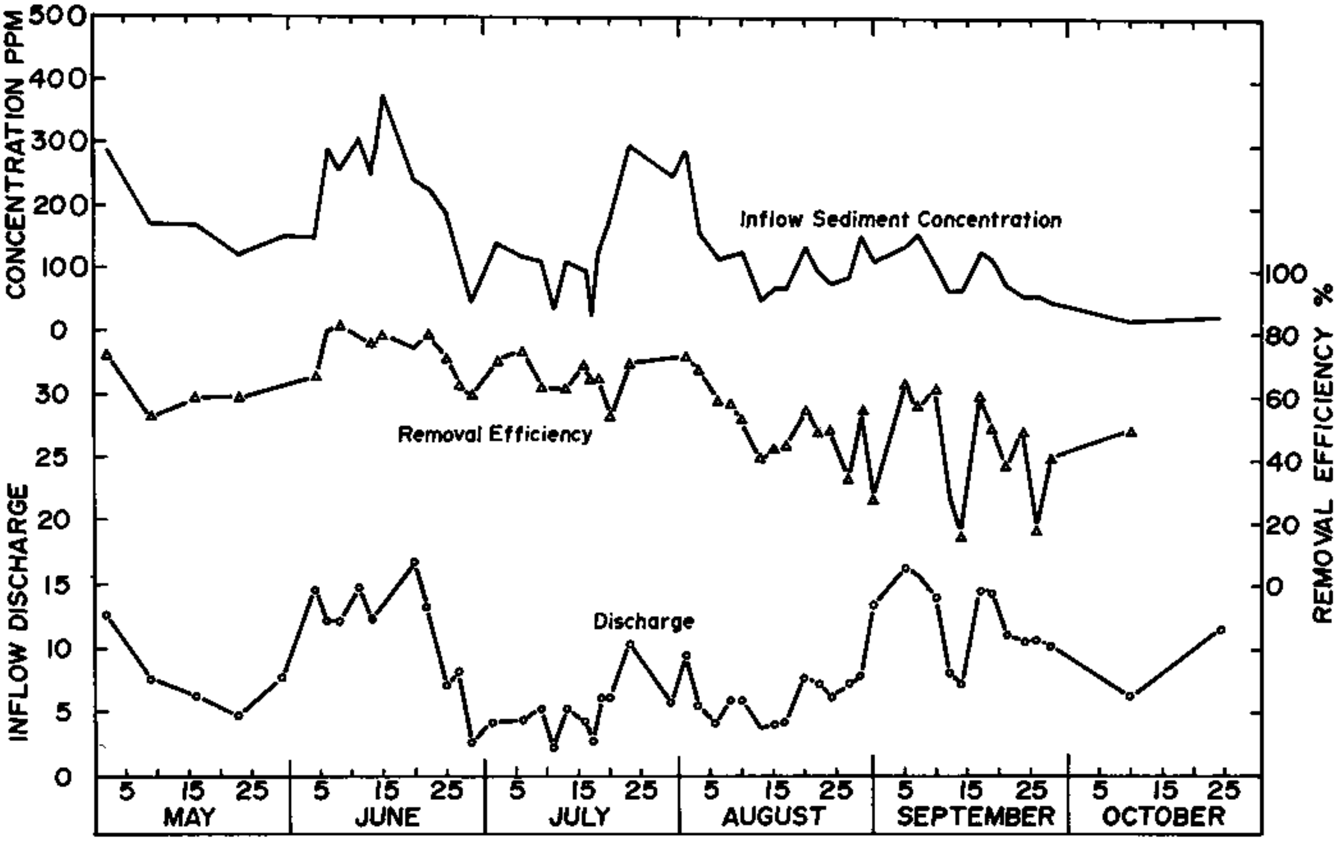


Figure 4. Discharge, inflow sediment concentration and removal efficiency, K-Lateral pond, 1973.

clay particles were transported and these cannot be settled out in this type of pond.

Data from the K-Lateral pond (Fig. 4) show that sediment concentration in the runoff water was closely correlated with the flow rate throughout the irrigation season. Removal efficiency correlated well with flow rate and sediment concentration. Near the end of the season, more regulation waste and less runoff from cultivated fields reduced both sediment concentration and removal efficiency.

Seasonal removal efficiency of the K-Lateral sedimentation pond was 68% in 1972, 65% in 1973, and 74% in 1974 (Table 1). Although removal efficiency was higher in 1974, the total flow was greater. Therefore, since the outflow sediment concentration was about the same as previous years, the total sediment discharged from the pond was greater.

An idealized, triangular-shaped pond would fit very well into a natural draw or swale. An inlet section probably should be excavated to allow adequate space for deposition of the heavier and larger particle sizes. The outlet would be an embankment which would easily permit installation of a skimming weir exit. For intermittent flows, which may occur in urban areas under storm runoff, a grass filter strip could be planted on the embankment. A control section, probably a concrete strip or preferably a concrete-lined ditch, would be needed to prevent embankment erosion. If there is a continuous flow, a small concrete (or other) lined spillway would be needed. Hydrologic data on the basin would be needed to adequately size the sedimentation pond and the outlet structure.

Table 1. Flow and sediment, K-Lateral sedimentation pond 1972, 1973, 1974.

Year	1972	1973	1974
Avg. flow rate (cfs)	10.96	9.60	11.44
Total flow (ac/ft)	4045	4285	5140
Sediment (sampling)			
Concentration in (ppm)	230	150	220
Concentration out (ppm)	70	50	60
Avg. removal (%)	68	65	74
Range removal (%)	36-77	20-75	0-90
Removed (t)	757	456	945
Passed (t)	361	243	324
Sediment (surveying)			
Removed (t)	502	562	810
Removed (yd^3)	465	520	750

In the rural and irrigated agriculture areas, sediment collected in sedimentation ponds can be used to fill gullies or to relevel fields so that runoff and erosion are reduced. In the urban areas, advanced planning will be required to insure that space is available for disposal or use of the sediment collected in a sedimentation pond.

A triangular-shaped sedimentation pond with uncontrolled inflow will be constructed for the 1975 irrigation season. Two rectangular ponds, one 75 × 300 ft and one 150 × 300 ft, arranged so that flow rate and exit conditions can be controlled for research purposes, have been constructed for the 1975 season.

Summary

Sedimentation ponds can effectively reduce sediment concentrations in runoff streams. A 60 × 500 × 5 ft pond on an irrigation return stream has removed about 70% of the incoming sediment from a 10 cfs stream and collects about 600 t/yr of sediment.

An idealized pond shape would be triangular with a narrow inlet and a wide exit which would allow a continually decreasing forward velocity and/or a decreasing settling depth, and would retain particles as small as the upper clay fractions. The triangular-shaped pond fits well in natural runoff channels.

References

1. Ballard, F. L. 1975. Analysis and Design of Settling Basins for Irrigation Return Flow. Unpublished M.S. Thesis, Univ. of Idaho, Moscow.

2. Brown, M. J., D. L. Carter, and J. A. Bondurant. 1974. Sediment in Irrigation and Drainage Waters and Sediment Inputs and Outputs for Two Large Tracts in Southern Idaho. J. Environ. Qual. 3(4):347-351.

3. Camp, T. R. 1936. A Study of the Rational Design of Settling Tanks. Sewage Works J. 9(5): 742-758.

4 Camp, T. R. 1946. Sedimentation and the Design of Settling Tanks. Trans. ASCE, 3:895-958.

5. Camp, T. R. 1953. Studies of Sedimentation Basin Design. Sewage and Industrial Wastes 25(1):1-14, Jan.

6. Carter, D. L., C. W. Robbins, and J. A. Bondurant. 1973. Total Salt, Specific Ion, and Fertilizer Concentrations and Balances in Irrigation and Drainage Waters of the Twin Falls Tract in Southern Idaho. USDA-ARS W-4.

7. Culp, G. 1969. A Better Settling Basin. American City 84(1):82-85, Jan.

8. Hazen, A. 1904. On Sedimentation. Trans. ASCE 53:45-88 (Paper #980).

9. Howard, C. W. 1953. Density Currents in Lake Mead. Proc. Minnesota Internatl. Hydraul. Convention.

10. Stokes, G. G. 1851. On the Effect of Internal Friction of Fluids on the Motion of Pendulums. Trans. Camb. Phil. Soc. 9:8-106.